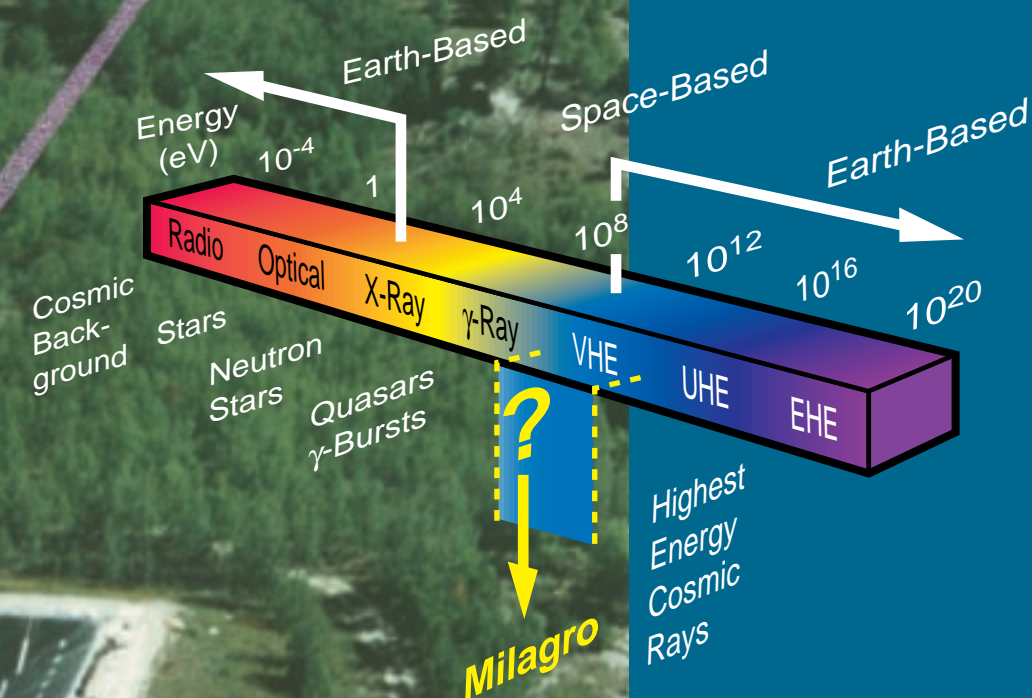
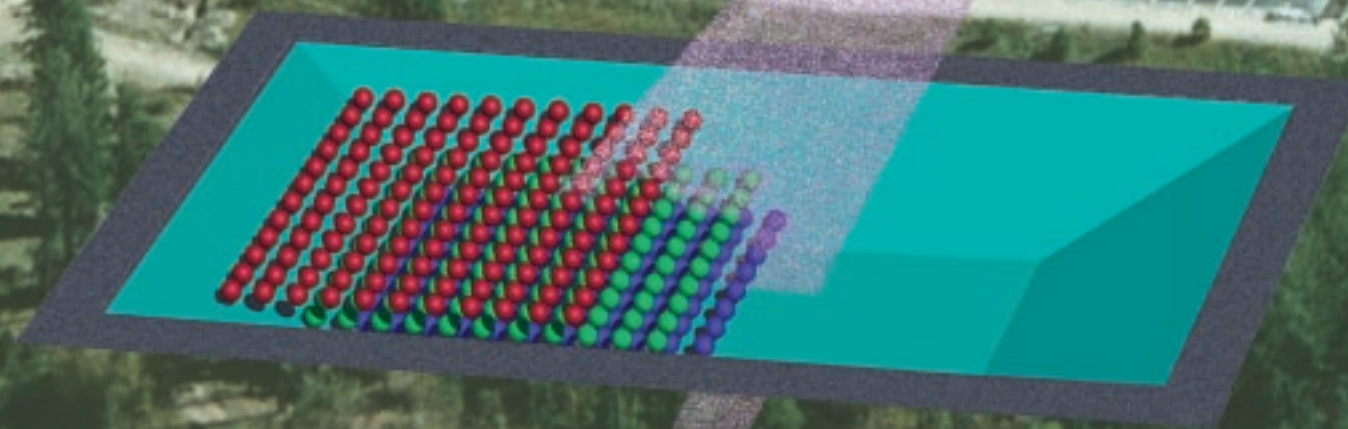


I. Group Descriptions



The Milagro Gamma-Ray Observatory at Fenton Hill in the Jemez Mountains uses hundreds of sensitive, light-detecting photomultiplier tubes submerged in a five-million-gallon artificial pond to record signals from high-energy cosmic emissions.



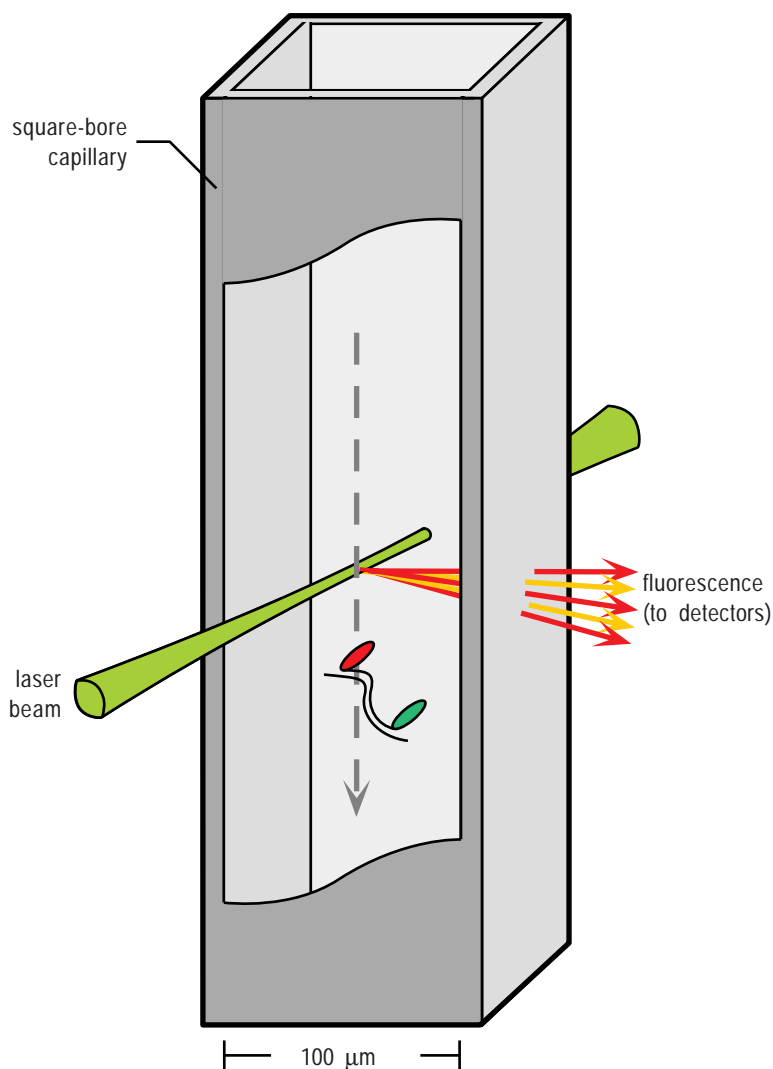
P-21: Biophysics

C. C. Wood,
Group Leader
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Fig. I-1. Two nucleic-acid probes that complement a targeted sequence are labeled with different fluorescent markers. If the target molecule is present, both probes will bind to the target and reveal it by responding simultaneously when illuminated by the laser-based, ultrasensitive fluorescence system.

Introduction

The Biophysics Group (P-21) was founded in 1988 with the goal of applying the scientific and technical resources of Physics Division to the biosciences. The mission of P-21 is to apply physics knowledge and techniques to increase our understanding of important biological phenomena and to use biological systems to elucidate physical principles of complex phenomena. The group has strengthened existing biological projects within the Division and has initiated new bioscience efforts in a number of directions. Group members are engaged in biophysical research over a wide range of physical scales, including characterization of the structure and dynamics of protein molecules and the implications of those qualities for protein function; ultrasensitive detection and characterization of individual molecules using laser fluorescence; design and implementation of biologically inspired robots and adaptive digital hardware; development, validation, and application of noninvasive techniques for the measurement of human brain function; development of nonbiological applications of low-field magnetic sensors; and development of three-dimensional computational models of the human brain.



Single-Molecule Detection

P-21 and its collaborators have extended their work on the detection and characterization of single molecules in a liquid. The goal of this research is to measure and characterize the spectroscopic properties of individual molecules. Such spectroscopic measurements can be used to identify the presence of a particular molecular species in an extremely dilute solution, or they can be used to probe the local environment that surrounds an individual molecule. The former capability promises a new level of speed and sensitivity for medical diagnostics, whereas the latter capability makes it possible to study properties of biological systems that cannot be measured when a lack of sensitivity confines measurements to the determination of the average properties of a large ensemble of microenvironments. Thus far, the spectroscopic properties measured at the single-molecule level include emission spectra, fluorescence lifetime, and total emission intensity. Recently the single-molecule spectroscopic approach has been extended to include single-molecule electrophoresis and approaches to ultrasensitive detection of viral and bacterial pathogens in soil and water samples. We are exploring additional applications for basic research and for medical diagnostics (Fig. I-1).

Protein Dynamics Studies

The goals of P-21 studies of protein dynamics are to describe protein motion in atomic detail and to understand the consequences of dynamics for protein function. Our approach is to bring crystals of the CO-complex of the protein myoglobin down to liquid-helium temperatures, photolyze the CO with a flash of light, and observe the subsequent rebinding reaction with x-ray crystallography. We have constructed and tested a low-temperature Laue camera, determined the freezing conditions for the CO crystal that maintain the high degree of order required for Laue diffraction, and analyzed diffraction patterns obtained at 5 K. The results of this approach have accomplished the long-sought goal of characterizing the changes in the three-dimensional structure of a protein as it binds to a ligand (I. Schlichting, J. Berendzen, G. N. Phillips, and R. M. Sweet, "Crystal Structure of Photolyzed Carbonmonoxymyoglobin," *Nature* **371**, 808 [1994]).

Cryo-Crystallography

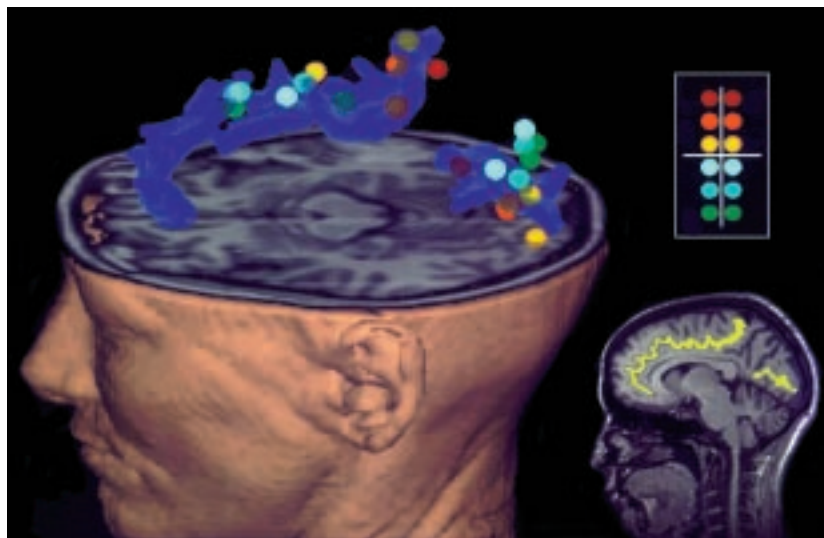
Cryo-crystallography is being extended to studies of electron transfer in the photosynthetic reaction center and to the understanding of proteins important for bioremediation of trichloroethylene (TCE) and other soil and groundwater pollutants. P-21 is part of a multidisciplinary Los Alamos effort that seeks to enable bioremediation of TCE by genetically engineered microorganisms. The first step in this effort is obtaining a thorough understanding of the enzymatic mechanisms by which TCE can be degraded. We would like, in effect, to watch proteins at work chewing up TCE. In a collaboration with scientists at U.S. universities and at the Max Planck Institute in Germany, members

of P-21 have begun to unravel the mystery surrounding the mechanism of one class of enzymes that might be engineered to degrade TCE, the cytochrome P-450s. P-450s bind molecular oxygen, split the dioxygen bond, and insert one oxygen atom into organic substrates. This can be the first step in the biodegradation of TCE. The reaction is also a crucial step in steroid hormone synthesis, and P-450s are important targets for drugs to treat breast cancer and other malignancies.

Noninvasive Imaging Techniques

The P-21 neuroscience effort focuses on the use of magneto-encephalography (MEG) and magnetic resonance imaging (MRI) to develop improved techniques for noninvasive imaging of the human brain. MEG involves the use of superconducting quantum interference devices (SQUIDs) to measure magnetic fields associated with human-brain activity. Measurement of the magnetic fields of the brain (which are approximately a billion times smaller than that of Earth) requires sensitive magnetic sensors, magnetic shielding from the environment (currently implemented through a shielded room), and advanced signal-enhancement and modeling techniques. Because magnetic fields readily penetrate the skull, MEG offers the potential for non-invasive measurement of brain function in much the same way that computed tomography and MRI allow the noninvasive detection of brain structure. MEG has therefore generated considerable interest in its possible use as a tool in basic neuroscience for functional mapping of the human brain (Fig. I-2), as a clinical tool for the assessment of neurological and psychiatric disorders, as a possible source of signals for use in the development of neural prosthetics and human-machine interfaces, and in other applied contexts. Group members are engaged in projects to design improved multichannel magnetic sensors, to develop more accurate mathematical models for localizing the electrical and magnetic signals from the brain, to validate MEG using known current sources in computational and physical models of the brain, and to

Fig. I-2. The small, colored spheres represent active regions of the cortex along the cingulate sulcus and the calcarine fissure (upper and lower blue structures, respectively) that are responding to small patterns of light from various positions in the visual field (see corresponding spheres in the inset). Systematic mapping is evident: stimuli placed in the upper visual field activated posterior regions of the cingulate sulcus and lower regions of the calcarine fissure; lower-field stimuli activated anterior regions of the cingulate and upper regions of the calcarine.



use MEG to address important questions in basic neuroscience and in research on neurological and psychiatric disorders. Many of P-21's neuroscience projects are conducted in collaboration with the New Mexico Institute of Neuroimaging, a consortium that includes Los Alamos, the University of New Mexico, and the New Mexico Regional Federal Medical Center and is sponsored by the U.S. Department of Veterans Affairs.

Combining MEG and anatomical MRI with other functional imaging techniques such as functional MRI (fMRI) and positron emission tomography (PET) offers the opportunity of increasing the combined spatial and temporal resolution of functional imaging techniques well beyond that of any single method. P-21 is engaged in developing mathematical models for combining these alternative forms of brain imaging. This work is part of a nationwide effort to develop three-dimensional computational models of the brain in which a variety of structural and functional information can be represented for storage, retrieval, and analysis.

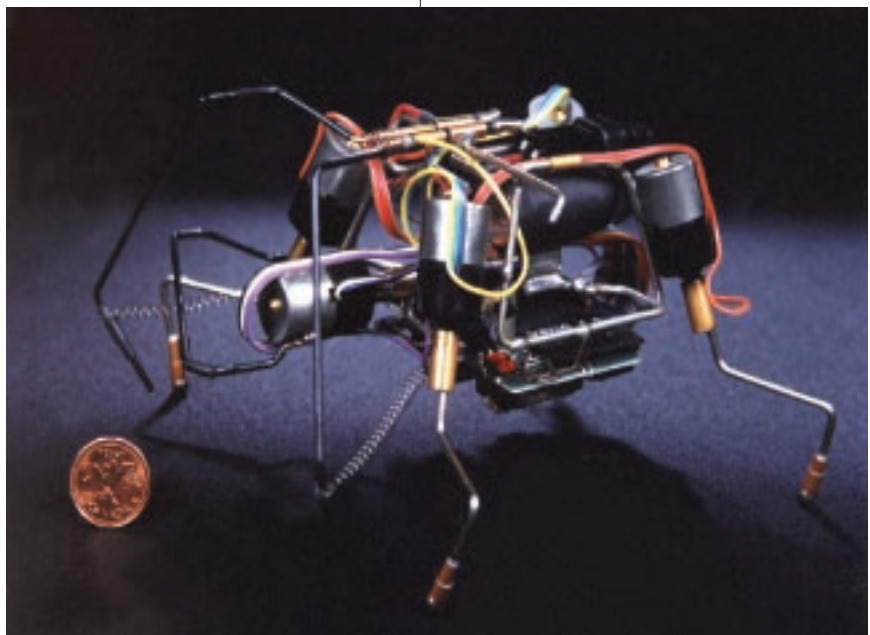
Low-Field Magnetic Sensors

The P-21 low-field magnetic sensor effort has recently been extended to apply low-field sensors to nondestructive evaluation (NDE) of materials, detection of underground objects, and a number of applications in nonproliferation. These applications take advantage of a number of recent Los Alamos developments, including new concepts in superconducting weak-field sensor arrays, the introduction of digital signal processors (DSPs) into the SQUID circuit, and improved high-temperature superconducting (HTS) Josephson junctions for HTS SQUIDs. The resulting sensors will be designed to operate in relatively hostile electromagnetic environments.

Adaptive Control Systems

P-21 has begun investigations into the design, implementation, and application of a variety of adaptive control systems. These include development of biologically inspired, legged robotics with simple, highly robust control circuits (Fig. I-3); applications of wavelets for feature recognition and data compression; and support for advanced multi-channel data-acquisition systems. This work promises to contribute both to an improved understanding of robotic control and to a variety of applications in which robust, inexpensive adaptive capabilities are required.

Fig. I-3. Turtle 1.5, a first-generation "biomech" walker, self-optimizes its gait over various terrains, even after considerable damage. Its analog control system adapts to such situations without the need of any programming.



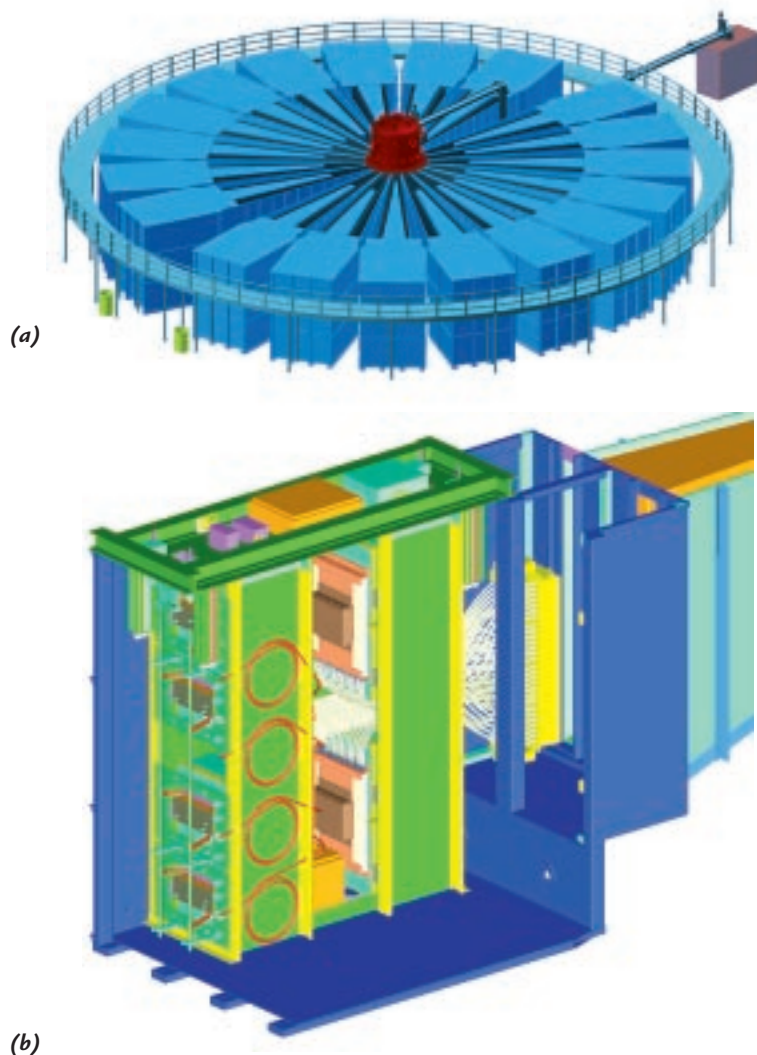
P-22: Hydrodynamic and X-Ray Physics

Joseph S. Ladish,
Group Leader
Jack Shlachter,
Deputy Group Leader (1997)
R. Richard Bartsch,
Deputy Group Leader (1996)
Mary Hockaday,
Deputy Group Leader
(1995–1996)

Introduction

The mission of the Hydrodynamics and X-Ray Physics Group (P-22) is to solve challenging experimental physics problems relevant to our national security, particularly when we can reduce the threat of war by helping to ensure the reliability of our nuclear-weapons stockpile and by limiting the proliferation of weapons of mass destruction. We continue to maintain and develop as national assets a creative, multidisciplinary team and state-of-the-art technology. To fulfill its mission, the group maintains a broad physics and engineering capability and pulsed-power facilities. Physics disciplines include hydrodynamics, x-ray spectroscopy and imaging, plasma physics, radiation hydrodynamics, optics and fiber optics, microwaves, electromagnetics, atmospheric physics, and atomic physics. Engineering disciplines include analog and digital electronics; electro-optics instrument design and fabrication; high-voltage, low-inductance, pulsed-power engineering; and fast-transient data recording. P-22 is the home of the Pegasus II Pulsed-Power Facility and of the future Atlas High-Energy Pulsed-Power Facility (Fig. I-4).

Fig. I-4. (a) Detail of the heart of the design for Atlas, showing oil tanks (in blue) that will hold the Marx units, the troughs containing the transmission lines (in black), the target chamber (in red at the center), and the vacuum line and evacuation system (the black pipe leading to the brown tank). Each of the oil tanks will contain thirty-two 60-kV capacitors. The two 55-gal. tanks on the left show the size of the designed machine. (b) Cross section of the lower half of one of the maintenance units, showing four large capacitors and the isolation switches for each pair of capacitors.



Nuclear-Weapons Program Research

The mainstay of P-22 has been its support of the nuclear-weapons program. P-22 applies the scientific and engineering expertise that it developed for the nuclear test program to investigate and understand crucial weapons-physics issues in a world without nuclear testing. The foundation of the present Los Alamos nuclear-weapons program is Science-Based Stockpile Stewardship (SBSS), which requires the development of complex experiments on diverse facilities to address the relevant physics issues of the enduring stockpile.

P-22 continues to field experiments underground at the Nevada Test Site (NTS), both to maintain our readiness to support a resumption of nuclear testing, should the need arise, and to study the physics of weapons performance and materials. These experiments increase our understanding of weapons science by allowing improvements in code calculations and in estimates of the severity of problems and changes occurring in the nuclear stockpile as it ages. At present, we are fielding experiments to measure the equation-of-state properties and spall strength of weapons-grade plutonium. We are also designing experiments and developing diagnostics to measure the properties of material ejected when plutonium is shocked by a high-explosive detonation. By performing these experiments underground at NTS, the plutonium is handled and contained in a manner similar to that used for underground nuclear tests.

In the portion of the weapons program involving above-ground experiments (AGEX-1), we are developing diagnostics to study the physics of the release of high-pressure shock waves. Diagnostics under development include the following:

- visible-wavelength and infrared pyrometers to determine the temperature history of a shocked surface;
- a very-short-pulsed laser and an ultrafast streak camera to determine by elastic backscattering the density and size of an ejecta cloud of fine particles, particularly when the particles are too small to be identified by holography;
- low-energy x-ray sources for imaging of low-density material from shocks;
- a reflectivity diagnostic to determine whether the surface of a shocked sample has melted; and
- a measurement of the speed at which moving, high-density material can produce a fiber-optic signal.

These diagnostics will be used to study shocks produced by explosives, gas guns, and the Pegasus capacitor bank.

In other AGEX-1 work, we are supporting the development of the Dual-Axis Radiographic Hydrotest Facility (DARHT) by studying the beam physics of DARHT's technical precursor, the Integrated Test Stand (ITS). We have built and fielded a magnetic spectrometer to measure the beam energy as a function of time in

the 70-ns ITS pulse. We are developing a microwave diagnostic to measure nonintrusively the beam electron density, and we are participating in the planning of new advanced radiographic facilities. We built and tested an elastic-backscattering lidar system that can find, track, and map out the shape of the effluent cloud from a small high-explosive detonation miles away, even when the cloud is invisible. The lidar can direct equipment, such as a remotely piloted airplane, to sample the effluent cloud to determine the presence of hazardous materials.

As part of the High-Energy-Density Physics (HEDP, formerly AGEX II) program, the 4.3-MJ Pegasus II Pulsed-Power Facility is used to drive experiments in which the weapons community is interested. Pegasus II can be used as a radiation driver or as a hydrodynamic driver in convergent geometry. Experiments are being performed to investigate nonsymmetric hydrodynamic flow and ejecta formation of shocked surfaces. In addition, pulsed-power research on improved radiation drivers, fast vacuum switching, and power flow channels are being pursued as we look to the future requirements of Atlas and explosive pulsed-power systems. P-22 has provided pulsed-power and diagnostic expertise to Procyon, Ranchito, and Ranchero, the Laboratory's high-explosive pulsed-power systems.

P-22 is the home of Atlas, the next-generation 36-MJ pulsed-power facility. The year 1996 marked the official start of the Atlas construction project, with the first dollars arriving for detailed facility design. Atlas will provide advanced radiation and hydrodynamic capabilities for weapons-physics and basic research. Research and development activities have centered on component development, prototype design and testing, and investigation into how the physics of interest scales to higher energies. The present design would provide operation at 240 kV, 480 kV, and 960 kV, allowing a wider scale of experiments to be performed than in earlier conceptual designs.

P-22 is deeply involved in protecting and archiving the volatile test data it took during more than three decades of underground nuclear testing. Our goal is to bring the group's data to a stable and readily accessible state. These data will be used to benchmark all future calculational tools.

In another part of the HEDP program, P-22's plasma-physics expertise and ability to do large-scale integrated experiments have provided group members with the opportunity to participate in several collaborations with the premier All-Russian Institute of Experimental Physics at Sarov, Russia (VNIIEF), the weapons-design laboratory that is the Russian counterpart of Los Alamos. In addition to giving us the chance to learn about some of the Russians' unique capabilities, the collaborations provide Russian weapons designers with an opportunity to do peaceful basic-scientific research and to integrate themselves into the world's broader scientific community. These collaborations are based on our

mutual interests in high-explosive-driven pulsed power, wherein the Russians have clearly demonstrated scalability to large systems that is unmatched to date in the United States. P-22 is participating in experiments on the Russian MAGO system, a possible candidate for magnetized target fusion; in attempts to convert a frozen rare gas to a metal by compressing it in a large magnetic field; in the design and testing of a thin, imploding cylinder for a megajoule x-ray source; and in studies of the properties of materials at cryogenic temperatures in magnetic fields up to 1000 T.

The group has two vacuum ultraviolet beamlines and two x-ray beamlines at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory (BNL). These beamlines, which cover the photon energy range from 30 eV to 20 keV, are used to calibrate detectors and to pursue research. Over 100 detectors were calibrated for use in HEDP experiments this year. Presently group members are studying electron-electron interactions in atomic systems by measuring the multiple ionization in rare gases near their respective K-edges. These measurements require the tunability and resolution of the synchrotron x-ray source to further delineate the limitations of the one-electron model.

Technology Transfer

P-22 has increased its involvement in technology transfer with several cooperative research and development agreements (CRADAs). Our knowledge of Faraday fiber-optic sensors is being applied to provide active feedback of the speed of the wheels of large trucks during braking. This work has recently been submitted for a patent. A debris-free, electron-beam-driven lithography source at 130 Å is being developed in conjunction with LANSCE Division and Northrup Grumman Corporation. This effort is an attempt to use the predicted anomalous energy loss of a short-pulse (subpicosecond) electron beam in a preformed plasma to heat and further ionize the ions to a charge state such that efficient 130-Å emission will occur.

Challenging engineering problems must be solved for experiments to succeed. Such challenges include the remote control of instrumentation, specific instrument performance, and package design for both laboratory and field environments. P-22 has an in-house capability to design, prototype, and characterize new components and systems with specialization in microelectronics, high speed, and optoelectronics. Industrial interactions include work with IBM and Motorola through CRADAs and funds-in-agreements.

Our integration of broad experimental physics and engineering expertise enables the group to fulfill its mission and opens the door to exciting future opportunities.

P-23: Neutron Science and Technology

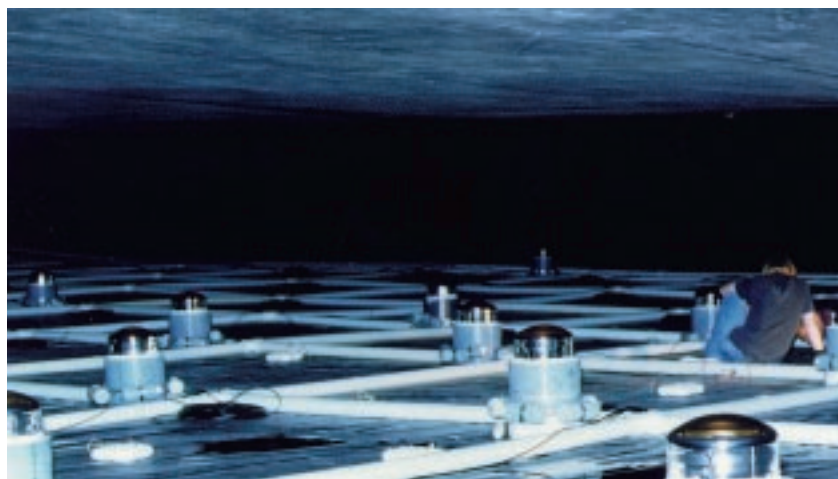
Mary Hockaday,
Group Leader (1997)
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Introduction

Group P-23 (Neutron Science and Technology) applies its extensive experience in both particle detection and the recording of transient events to support the experimental program at the Los Alamos Neutron Science Center (LANSCE), to participate in a variety of Nuclear Weapons Technology (NWT) projects, and to carry out basic research in fundamental and applied physics. The work at LANSCE involves support of Laboratory programs in Science-Based Stockpile Stewardship (SBSS), Accelerator Production of Tritium (APT), and Energy Research (ER). The NWT projects in which P-23 participates include subcritical experiments; nonnuclear hydrodynamic experiments (AGEX-I) at either LANL or the Nevada Test Site (NTS); pulsed-power experiments for the High-Energy-Density Physics (HEDP) program; and archiving and analyzing data from past nuclear-weapons tests. The group's work in fundamental research focuses on nuclear and weak-interaction physics and on astrophysical phenomena involving the detection of solar neutrinos and ultrahigh-energy gamma rays. Applied research conducted by the group includes the development of quantum-information technologies, such as quantum computation and encryption (involving single-photon detection) and the application of imaging and neutron technologies to problems relevant to national defense or industry.

P-23 provides and improves imaging technologies including tomography and holography, wide-dynamic-range data acquisition and recording, and spectral measurements involving the detection of photons across 13 orders of magnitude in energy (infrared to ultrahigh-energy gamma rays) and neutrons across 15 orders of magnitude (ultracold neutrons to 800 MeV). The major experiments in which the group is involved are located at the following facilities: LANSCE, at both the Manuel Lujan Jr. Neutron Scattering Center (MLNSC) and the Weapons Neutron Research (WNR) facility; NTS; the Pegasus pulsed-power facility at Los Alamos; the Milagro site in the Jemez Mountains for detecting ultrahigh-energy photons from outside the solar system (Fig. I-5); off-site accelerators; and the Sudbury Neutrino Observatory (SNO) in Canada.

Fig. I-5. Installation of the first set of photomultiplier tubes in the Milagro detector.



LANSCE Support

Data from previous weapons tests do not provide all of the data that we presently believe are required for the weapons laboratories to be able to assure the safety and reliability of the nuclear-weapons stockpile without nuclear testing. NTS experiments answered only a small part of the question of what happens to a weapon as its components age. The SBSS program is intended to put this and other assurance issues on a scientific basis without nuclear testing. Together with our colleagues in other groups, divisions, and laboratories such as Lawrence Livermore National Laboratory (LLNL), we are studying the following:

- the performance of chemical explosives, including changes as they age;
- the fundamental physics of plutonium, e.g., the phonon spectrum;
- the temperature of materials undergoing hydrodynamic instabilities; and
- nuclear cross sections that are required for better analysis of radiochemical data from previous weapons tests.

For these studies we use neutrons from LANSCE, including moderated neutrons from the MLNSC, moderated neutrons with tailored time-structure from the WNR “Blue Room,” and unmoderated neutrons from the WNR fast-neutron source. Neutron spectroscopy by time-of-flight techniques is central to all of these projects.

In support of the SBSS program, research in nuclear physics is carried out at the WNR facility with neutrons from below 1 MeV to 800 MeV. A large array of Compton-suppressed germanium detectors (the GEANIE detector) has recently been installed to measure, with very high resolution, gamma rays from neutron-induced reactions. This is a joint project between LLNL and P-23, with additional participation by universities and other LANL groups. Nuclear structure and nuclear reactions can be studied with this new capability, which is described in detail in a Research Highlight of this Progress Report. Our interests at present are in the $^{239}\text{Pu}(n,2n)^{238}\text{Pu}$ cross section, where different nuclear-reaction models give markedly different predictions, and in the nuclear structure area of “complete spectroscopy,” where models of nuclear-structure symmetries and the transition from order to chaos in nuclear spectroscopy can be tested.

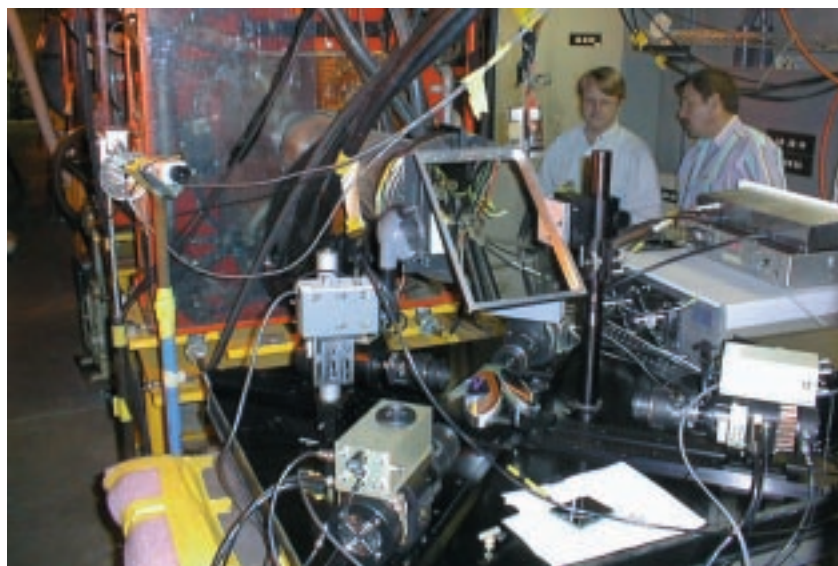
An important element of the SBSS program at LANSCE is hadron radiography. P-23 is supporting this effort with a cold-neutron radiography project at the MLNSC, by participation with P-25 and LLNL in the 800-MeV proton-radiography project at LANSCE, and in the high-energy neutron-radiography project at WNR. P-23 developed a cooled, charge-coupled device (CCD)

imaging system with fast gating and image intensification for use in hadron radiography (Fig. I-6). The system was first applied to radiograph a low-density material encapsulated in a high-density casing, using neutrons produced at the WNR in the 5- to 200-MeV energy range. The group has also collaborated with P-25 in the development of a pixelated, gas-amplification wire-chamber detector for hadron radiography.

As part of the SBSS program, P-23 has operated the WNR neutron sources and provided experimental support to experiments on the 6 beamlines at the WNR fast-neutron spallation source, WNR "Blue Room" experiments where the 800-MeV proton beam can be accessed directly, and 5 beamlines at the MLNSC. In the future, the operation of these facilities will be under the control of LANSCE Division, but we anticipate that technical experimental support will continue to be supplied by P-23.

The goal of the APT program is to explore the possibility of using accelerator-driven transmutation of helium to supply the U.S. nuclear-weapons stockpile with tritium. Production of tritium from traditional reactor sources was terminated in the late 1980s. Because tritium decays with a 12-year half-life, a continuing supply of tritium is necessary to maintain the stockpile at any given level. P-23 supplies basic nuclear-physics data, performs integral tests of the calculated neutronic performance of benchmark systems, develops beam diagnostics, and participates in irradiation studies of components for this program. Basic nuclear-physics data include neutron total and reaction cross sections and activation data, mostly measured with the spallation neutron source at WNR. Integral tests employ small-scale mockups of the accelerator target and of the neutron-reflecting blanket. These allow the initial neutron production, the final tritium production, and intermediate steps to be quantified and compared with calculation. Beam diagnostics utilize P-23's imaging capabilities. An important milestone was reached with the demonstration that the superconducting cavity continues to perform well even when irradiated directly with the

Fig. I-6. Shown in the lower half of this photograph are the four CCD cameras that P-23 operates as part of the dynamic proton-radiography project.



LANSCE proton beam. These data-measurement activities and integral demonstrations are continuing as the APT program progresses.

We work with LLNL and Ohio University at WNR on the measurement of neutron total cross sections. This quantity describes the probability of neutron interactions with materials and is therefore central to all calculations of neutron transport in macroscopic systems, such as targets and shielding in the APT project, nuclear weapons, proton- and neutron-therapy facilities, and basic nuclear-physics accelerator experiments. The WNR facility is ideal for these measurements because of its excellent neutron-source characteristics: a subnanosecond pulse width, low gamma-flash, and high repetition rate. Accuracies on the order of 1% are routine with this approach over a neutron energy range of 5–600 MeV. The data rate is high; the average run time necessary to achieve this accuracy for a given material is about 1 day.

Support of ER programs at LANSCE is described in the later section on Basic Research.

NWT Support

With the end of nuclear testing, our knowledge of the ways in which actual weapons work relies on the data that were obtained from tests at NTS and test locations in the Pacific Ocean. Saving, analysis, and documentation of NTS weapons test data is a major responsibility of P-23 and the other groups responsible for these measurements and is crucial to the success of SBSS. Fortunately, physicists and engineers who performed the original measurements are still available to analyze their data and correlate the data of different events. In addition, new scientists are being trained in the technologies of making such measurements in case the need should arise for future underground tests. P-23 concentrates on the analysis of pinhole neutron experiments (PINEX) imaging data and on neutron emission measurements (NUEX and THREX). These data complement reaction history and radiochemical measurements, which are made by other groups. The process of saving, reanalyzing, and documenting these data has allowed us to obtain a better understanding of the underlying physical processes that generated them. Comparison of the results from different tests is allowing us to study systematically the behavior of nuclear explosives.

If SBSS is to be successful in allowing us to certify the performance of our nuclear weapons in the absence of nuclear testing, we must develop better physics models and incorporate them into computer codes that calculate explosive performance. We must be able to validate these codes against the NTS data that we have. Only then will we be able to address with confidence the issues of aging and remanufacture of our stockpile weapons.

P-23 is participating in a series of experiments to explore weapons-physics issues of a more microscopic nature than those explored in the underground NTS tests of nuclear explosives. We use chemical explosives and pulsed-power machines such as Pegasus as drivers to examine issues such as the equation of state (EOS) of shocked materials, formation and transport of ejecta from shocked surfaces, and growth of hydrodynamic instabilities. Underground experiments (UGEX) that involve plutonium are planned for the U1a facility at NTS. Experimental tools, such as gated visible imaging, gated x-ray imaging, holography, and infrared (IR) temperature measurements, are used to study the physical phenomena. We are developing fast IR imaging. The data that we can thus obtain are used both to understand the physical processes and, as computer models are developed, to benchmark the calculations. These experiments will greatly improve our understanding of nuclear-weapons physics.

A critical—and currently limiting—component to a number of Laboratory weapons-program experiments is an imaging sensor that can be gated (or shuttered) in the few-nanosecond to subnanosecond regime, can achieve a high frame (or data) transfer rate (up to 10^7 frames per second), has a high quantum efficiency (1% to 50%) and sensitivity (<10 photons per pixel detection), and covers the spectrum from visible light into the near IR (380 nm to 5 μ m in wavelength). Such advanced-technology imaging capability is not available commercially, and the technology for achieving such imaging is presently state of the art or in development. Prior to the cessation of testing, advanced imaging was required for underground shots at NTS, and the Laboratory (previously in J-12 and P-15, and then in P-23) had developed an in-house capability to meet the needs of the weapons program. After suspension of the underground testing program, the Laboratory's SBSS program is forging above-ground experiments (AGEX) that are again placing ever increasing demands on the imaging and technology development capabilities of the weapons laboratories. Some of the areas in which advanced technology imaging systems are required are the following:

- AGEX;
- subcritical UGEX at NTS;
- hadron radiography;
- shock break-out experiments;
- Advanced Hydrotest Facility diagnostics;
- LANSCE beam diagnostics;
- Trident, Pegasus, HEDP-program, and Atlas diagnostics; and
- plasma physics.

Basic Research

Excitations of complex nuclei are characterized by resolved, well-spaced levels at low excitation. As the excitation energy increases, the number of levels increases until the levels overlap and cannot, in principle, be resolved. The level density in this unresolved region may have underlying structure related to the levels that exist at low excitation. At very high excitation, it is generally believed that the nucleus behaves like a gas of neutrons and protons, a so-called Fermi gas. The transition from the ordered states at low excitation to the disordered Fermi gas is of great interest, both for the basic physics of phase transitions in nuclear matter and for modeling the nuclear reactions of astrophysics and nuclear explosives, where short-lived nuclides can contribute significantly to nucleosynthesis and to the dynamics of a reacting system. At WNR we are studying nuclear level densities through neutron-induced (n,z) reactions that produce charged particles, such as reactions where protons or alpha particles are produced. By studying the evaporation spectra, we can deduce the level density in excited nuclei. Furthermore, we have two other techniques for studying level densities, both of which rely on the intense neutron source at WNR and the fact that the (n,z) reactions can be studied as a function of neutron energy over a wide energy range.

Because of enhancements engendered by the relatively long lifetimes of their states, compound nuclei provide an excellent laboratory for studying violation of basic symmetries. We have observed parity violation in neutron resonance reactions for a large number of resonances in more than a dozen target isotopes. With techniques developed by P-23 and our partners, we are able to identify very weak p-wave resonances in which parity violation can occur and be observed with amplitudes of up to 10% of parity-conserving interactions. Nuclear theory predicted that the sign of the parity-violating effect should be random, and for all but one nucleus, it appears to be. The exception is ^{232}Th , where the violation for the eight resonances with the strongest effects are all of the same sign, which would have a less than 0.25% probability of occurring if the sign were indeed random. We have investigated all of the readily available isotopes at maxima in the p-wave strength function and therefore are bringing this research to a close. The case of ^{232}Th remains an enigma.

We are also active in other tests of fundamental symmetries in the beta decay of trapped atoms and of free neutrons. Sensitive tests of the parity-violating beta-spin asymmetry correlation in the decay of ^{82}Rb constitute one experimental sequence that we anticipate will yield results with a precision one order of magnitude greater than any previous experiment. In studies of the decay of the free neutron, we initiated the EMIT ("time" reversed) collaboration to pursue a search for time-reversal invariance violation (TRIV). For this we have designed an experiment that promises to be seven times more sensitive than previous experiments.

As a follow-on to these measurements, we are planning to study parity violation in the reaction $n + p \rightarrow d + \gamma$. We have demonstrated the feasibility of many aspects of this experiment. We demonstrated that it was possible to achieve the counting statistics limit when taking a current signal from a vacuum photo diode that viewed a CsI gamma detector at the projected rates of a parity-violation experiment. The magnetic-field sensitivity of the current signal was shown to be small— $2 \times 10^5 \text{ G}^{-1}$. The spectral densities of position and intensity drifts in the LANSCE beam were also very small.

Finally, we measured the total cross section of the neutrons of ^3He with an accuracy of 10^{-3} in the energy range 0.5–500 eV. This cross section is important in understanding the performance of the polarized ^3He spin filter that will be required for such an $n + p \rightarrow d + \gamma$ experiment and for studies of the beta decay of polarized neutrons.

The dispersion relation between parity violation in spin rotation and transmission has been investigated by our study of the parity-violating rotation of the plane of neutron polarization when a transversely polarized neutron beam passes through a sample of ^{139}La . Lanthanum-139 has a resonance at 0.734 eV that exhibits large parity violation in transmission. This experiment also serves as a prototype for future experiments to study time-reversal symmetry violation in neutron transmission.

The basic neutron-proton interaction is studied at WNR in two types of experiments: simple n - p scattering and the more complicated situation where a gamma ray is emitted when the two particles interact, called neutron-proton bremsstrahlung (NPB). Simple (elastic) n - p scattering at certain angles and energies is sensitive to the interaction mediated by the exchange of a single π -meson, which is the most basic of interactions in meson-exchange theory. Despite decades of work on this interaction, there still is significant disagreement on the fundamental pion-nucleon coupling, and we are working to resolve this disagreement, which has widespread ramifications in the binding of nuclei and in astrophysics. Basic interaction models also give different predictions for NPB, which has not been studied before with differential measurements. The measurements are now being made by a group from the Massachusetts Institute of Technology together with P-23.

Ultracold neutrons (UCNs) were first produced at LANSCE in 1996 by the use of a rotor reflector. These neutrons travel with speeds of less than 8 m per second. We are continuing to develop this source with improved cold moderators and better rotor

reflectors (Fig. I-7). We plan to use this source in the investigation of the radioactive decay of free neutrons and, possibly, in the search for an electric dipole moment (EDM) of the neutron. Both of these projects aim at detecting physics beyond the standard model of strong and electroweak interactions. P-23 is participating with P-25 and others in the design of an EDM experiment at the proposed long-pulse spallation source (LPSS) at LANSCE that will use UCNs produced by the inelastic scattering of cold neutrons in superfluid helium.

Very-high-energy gamma rays from the cosmos have been detected when they enter the atmosphere and produce an air shower of particles. The Milagro project, located in the Jemez Mountains above Los Alamos and inaugurated in 1995, is the construction and operation of a high-efficiency observatory for gamma rays in the energy range around 10^{14} eV. This observatory involves a joint project of Los Alamos and a large number of universities. It will be especially well suited for the study of episodic or transient gamma-ray sources, that is, for recording gamma-ray bursts. It is operational 24 hours a day, 365 days a year, and its field of view is nearly half of the sky. Milagro began providing operational data in 1996 and soon will be fully instrumented.

The number and spectrum of neutrinos from the sun continues to challenge our understanding of solar physics and neutrino properties. For many years we have worked with scientists from the Soviet Union and, now, the Former Soviet Union to detect neutrinos by using large quantities of gallium far underground in the Caucasus Mountains. This is the SAGE (Soviet-American Gallium Experiment) collaboration. The result from this lengthy study was that the number of neutrinos detected is about half of that predicted by the best solar and neutrino models. Now we are

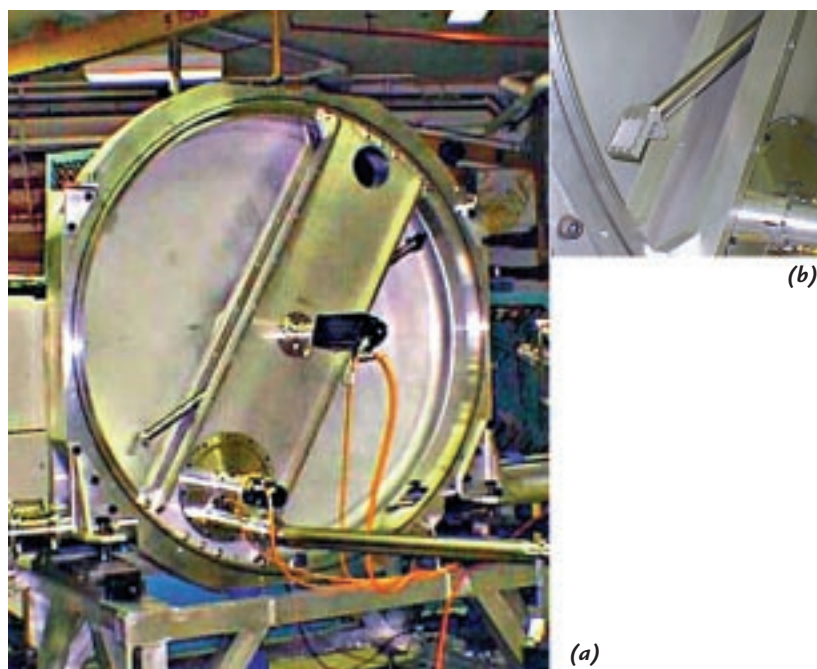


Fig. I-7. (a) UCN rotor with (b) a close-up of the mica crystal package.

collaborating in the development of a neutrino observatory more than a mile underground in Sudbury, Ontario. The SNO (Sudbury Neutrino Observatory) detector will soon be operational and consists of an acrylic vessel holding 1,000 tonnes of heavy water surrounded by another vessel with 8,000 tonnes of light (regular) water. All three flavors of neutrinos (electron, muon, and tau) will be detected. Development of this detector includes the design and fabrication of very-low-background ^3He detectors and new electronics. As a spin-off, the very sensitive, low-background detectors developed for the observatory will be used to screen high-density microelectronics for trace radioactive contaminants that can cause computer errors by “flipping” bit patterns.

Applications of Basic Research

Quantum computation, a field in its infancy, promises a new approach to solving some problems (regarded as intractable in classical computation) by using the quantum-mechanical superposition of many states (numbers) at once. To realize such a computer, we are developing a system with cold, trapped atoms that represent the quantum-mechanical states. Quantum logical operations are performed with laser manipulations of the states of the trapped atoms. Using conventional lasers, we have recently succeeded in trapping and imaging calcium ions that have the required spectroscopic structure to allow them to serve as basic quantum-mechanical bits. We are developing advanced diode lasers to perform the same operation, but with much reduced power requirements and cost.

Quantum mechanics provides an approach to unbreakable cryptographic codes that not only can transmit the code “key” with security but that can also reveal the presence of eavesdropping. We have demonstrated this quantum cryptography over 48 km of fiber-optic cable and are developing longer transmission demonstrations. In a related effort, we have demonstrated transmission of a “key” through more than 200 m of air and through this technology are aiming at establishing secure communications between ground-based stations and low-earth-orbit satellites.

Using the complementary wave- and particle-like nature of light, it is possible to determine the presence of an object without any photons being absorbed or scattered by it. We are carrying out fundamental studies in such “interaction-free measurements” and have begun investigating the practical implementation of “interaction-free imaging,” where these measurement techniques are used to take a (pixelated) image of an object, again with the goal of negligible absorption or scattering; at present, a resolution of better than $10\text{ }\mu\text{m}$ has been achieved, and we hope to improve this even further.

We support Department of Defense (DoD) programs in mine detection and seeker applications. For the detection of land mines, we are investigating the use of neutrons as an interrogating probe, with the detection of the resulting activation gamma rays as the positive signature. High-intensity neutron sources are necessary for the required sensitivity, and we are developing them in collaboration with other groups. Accelerator sources are strongly preferred because their energy can be tuned and specified, and they can be turned off when not in use. We are assessing the required sensitivity of detection, using our extensive experience acquired in developing neutron detectors for the Nuclear Test Program and for accelerator-based experiments. P-23 has also developed a laser-based, range-gated imaging system for the airborne detection of submerged mines. The system has undergone testing in both controlled-tank and open-sea environments. We have supported seeker (target identification) programs with range-gated laser distancing and ranging (LADAR) experiments carried out at the Wright Laboratory's laser range at Eglin Air Force Base. These experiments are part of a joint DOE/DoD technology-development program.

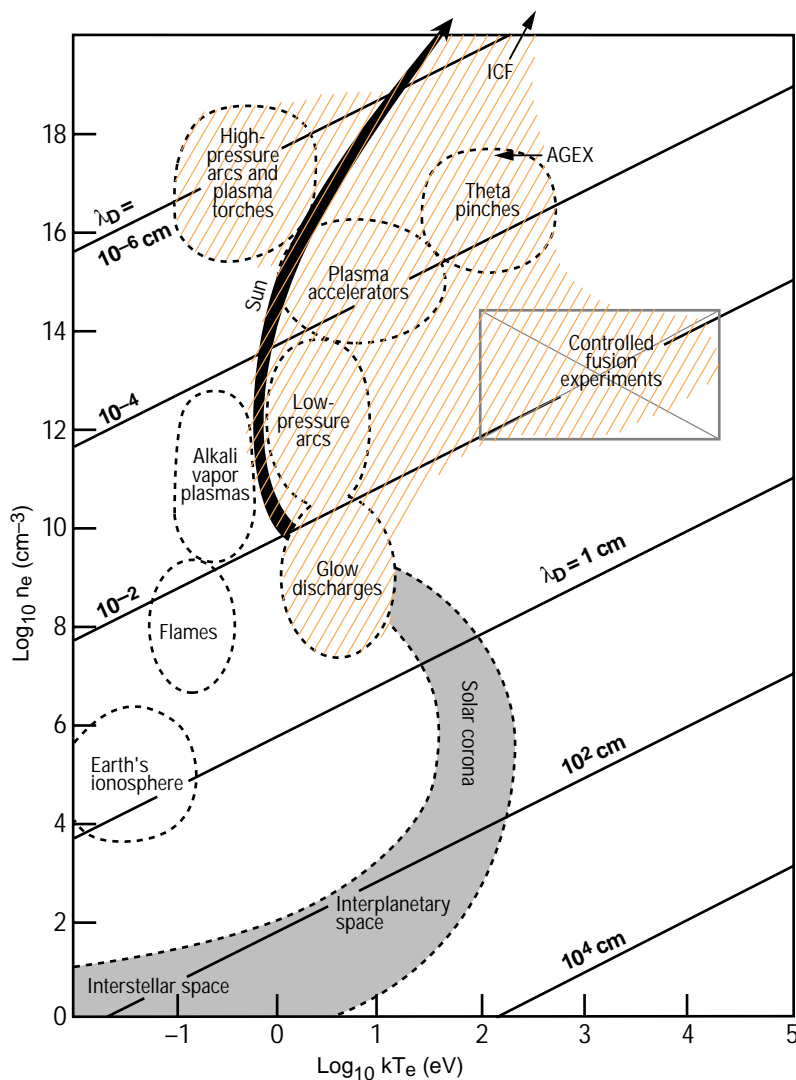
The further development of spallation neutron sources for basic physics research and for applications will depend on the availability of reliable targets that can withstand very high heat loads from accelerator beams. Together with researchers at the Institute for Physics and Power Engineering in Obninsk, Russia, we are developing a molten-metal target that promises to handle much higher heat loads than solid targets. Our Russian coworkers have had extensive experience in using molten-metal cooling in fission reactors. Using the intense, 800-kW LANSCE proton beam, our goal is to test their design of such a target. We are developing a small molten-metal test loop as a first step before the large Russian components are subjected to the full-intensity beam.

We are studying the feasibility of including a cryogenic source of UCNs in the design of the proposed LPSS. Preliminary indications are that if a frozen deuterium source could be operated at 5 K in a flux of neutrons at LPSS densities with a Maxwellian temperature of less than 80 K, it would produce usable UCN densities at least 400 times greater than those presently available anywhere in the world. Such a world-class source of UCNs at LANSCE would open up new opportunities for experiments in fundamental physics and the possibility of novel applications to materials science. P-23 will continue to provide guidance for this project throughout the preliminary and engineering phases of the LPSS design.

P-24: Plasma Physics

Kurt F. Schoenberg,
Group Leader
Juan C. Fernández,
Deputy Group Leader

Fig. I-8. Range of plasma temperatures and densities. The orange shaded region shows the regime of P-24 research. λ_D defines the fundamental scale length for plasma interactions.



Introduction

The Plasma Physics Group (P-24) investigates the basic properties of plasmas with a view to applications in important Laboratory and national programs. Plasmas occur in nature when matter exceeds temperatures of roughly 10,000°C. At these temperatures, the constituent atoms and molecules of matter begin to lose their bound electrons to form a substance composed of positive or negative ions and free electrons. All principal phenomena in plasmas can be traced to the fact that ions and electrons interact with each other through long-range electromagnetic forces. The electromagnetic interactions of groups of charged particles are often coherent, leading to collective modes of plasma behavior. This collective interaction of charged particles, a many-body problem, is the essence of the field of plasma physics.

Roughly 99% of the matter in the universe is in a plasma state. Plasmas can exist over a large range of temperatures and densities (Fig. I-8). For example, interstellar space contains plasmas with densities of less than one ion or electron per cubic meter at a temperature exceeding 1,000°C. In contrast, plasmas created by

intense laser compression of micropellets achieve densities of 10^{24} ions or electrons per cubic centimeter at temperatures exceeding 10,000,000°C. The understanding and application of such diverse plasmas forms the *raison d'être* of plasma physics, which is a Los Alamos National Laboratory (LANL) core competency.

P-24 is composed of a diverse technical staff with expertise in plasma physics, plasma chemistry, atomic physics, laser and optical science, and pulsed-high-power engineering. The group uses both on-site and off-site experimental facilities to address problems of national significance in inertial and magnetic fusion, nuclear-weapons stewardship, conventional defense, environmental management, and plasma-based advanced or green manufacturing. Our agenda includes basic research in the properties of energetic matter and applied research that supports the principal Los Alamos mission of reducing the nuclear danger. As shown in Fig. I-8 and discussed below, the pursuit of

this agenda entails the physics of plasmas over a wide and diverse range of conditions.

P-24's WWW site (<http://fjwsys.lanl.gov/>) contains information on our group's organizational structure and research.

Trident Laser Facility

Trident is LANL's multipurpose laboratory for conducting experiments requiring high-energy laser-light pulses. It is operated primarily for Inertial Confinement Fusion (ICF) research, weapons physics, and basic research, and it serves both LANL and external users. Features include flexible driver characteristics and illumination geometries, a broad resident diagnostic capability, and flexible scheduling. A dedicated staff maintains and operates the facility and assists the experimenters.

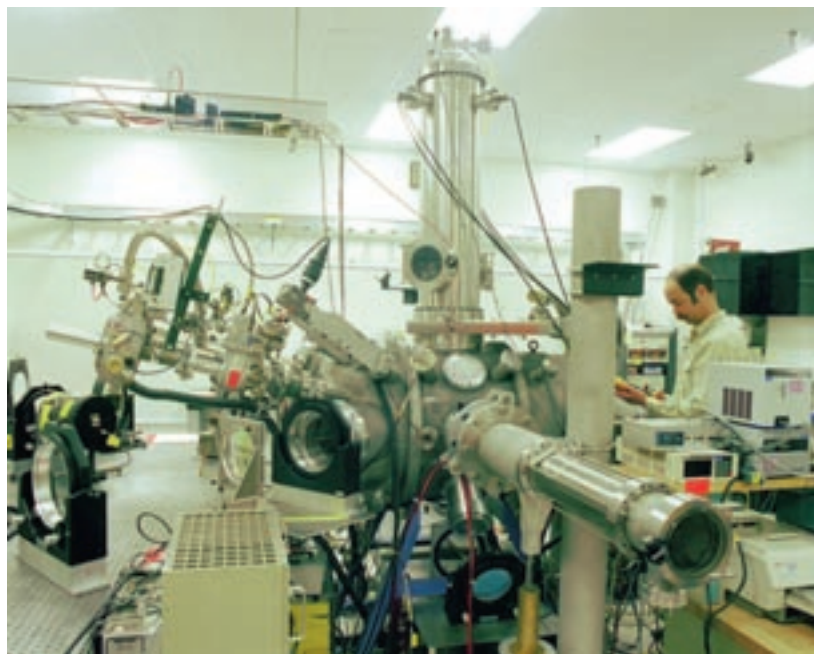
The principal resource at Trident is the laser driver. It employs a neodymium-doped, yttrium-lithium-fluoride (Nd:YLF) master oscillator and a chain of Nd:phosphate glass rod and disk amplifiers in a conventional master-oscillator, power-amplifier (MOPA) architecture. The oscillator output pulse is temporally shaped, amplified, split into two beams, amplified again, frequency-doubled, transported, and focused to the target. A third beamline can be used as an optical probe or to provide an x-ray backlighting capability. Its pulse can be either 100 ps in length or the same length and shape as those of the main drive beams. Although the third beamline is normally operated at 527 nm, fundamental (1054 nm) output of this beamline can also be used directly in the target chamber. The third beam can be timed to become active before or up to 5 ns after the main drive beams. The output of the master oscillator may also be frequency-broadened and "chirped" before amplification to allow compression to subpicosecond pulse lengths. Compressed pulses are presently available at the 1- to 2-J level at a separate target chamber in the front end, and we are anticipating compression of higher-energy pulses in the future.

The main high-vacuum target chamber is a cylinder approximately 150 cm long and 75 cm in diameter (Fig. I-9). Single- or double-sided illumination of targets is possible through several 20-cm-diameter ports on each end of the chamber. More than 40 smaller ports are available for diagnostic instrumentation. Individual targets are inserted through an airlock. The target insertion and positioning mechanism provides x - y - z and rotation adjustment under computer control with 1- μm linear and 0.01° angular resolution. The three-axis target-viewing system has 20- μm resolution. The chamber is fitted with a Nova-standard six-inch manipulator (SIM) to accept all SIM-based instruments for checkout, characterization, or use. Although Trident is conveniently located in an "open" area of the Laboratory, the target room can be secured administratively for classified experiments.

Optical diagnostics include illumination and backscattered light calorimeters, backscattered light spectrometers, and high-bandwidth (5-GHz) and streak-camera-based power monitors. Target x-ray emission is monitored by filtered, photoconductive diamond detectors and an x-ray streak camera with <10 -ps resolution. A Nova-standard, gated x-ray imager provides 16 gated, filtered x-ray images per nanosecond with a resolution of 80 ps. Various filtered x-ray power and spectral diagnostics can be installed as needed. These cover the energy range of 0–35 keV. Static x-ray pinhole cameras are also available. Most optical and target diagnostics are available for either the main target chamber or the ultrahigh-irradiance chamber.

Trident is available to Laboratory and outside experimenters. The quality of proposed research and its relevance to Laboratory missions are major criteria that the P-Division Trident Steering Committee considers in determining what experiments are fielded. Trident is operated by P-24 as a DOE user facility that principally

Fig. I-9. Target chamber of the Trident laser facility.



supports the ICF and Above-Ground Experiments (AGEX) programs. It is funded through and operated for the Nuclear Weapons Technology (NWT) ICF Program Office. The resources of the Laboratory's Target-Fabrication Facility, operated by the Materials Science and Technology (MST) Division, are also available to assist experimenters in designing, fabricating, and characterizing targets for Trident experiments.

We are actively pursuing a facility upgrade to the Trident laser that should occur in the next few years. As envisioned, the Trident Upgrade will be a flexible, high-shot-rate facility with the required performance for weapons-relevant research in materials properties and in the hydrodynamics of ionized matter. It will enhance the present Trident capabilities in experiments on laser-matter interactions and other fundamental-science topics. It will provide a staging capability to higher-energy-density facilities and will attract high-quality scientific research to stockpile stewardship.

For single-sided, long-pulse illumination, the Trident Upgrade will have similar capabilities to those of the world's two most powerful lasers, Omega and Nova, but with the capability of providing both classified shots and the use of special nuclear materials. In addition, the Trident Upgrade will function as a premier calibration, prototyping, and staging facility for the National Ignition Facility (NIF) and will provide a local, high-shot-rate facility for the LANL weapons-physics/ICF programs to prepare experimental concepts.

Inertial Confinement Fusion

The ICF program at Los Alamos is a principal component of the national ICF program, which is focused on the goal of achieving thermonuclear ignition of an inertially confined plasma in the laboratory. This national goal represents one of the grand scientific challenges of the 20th Century and supports the DOE Stockpile Stewardship Management Plan for nuclear weapons. In pursuit of the ICF mission, P-24 designs, diagnoses, executes, and analyzes the results from experiments in high-energy laser facilities worldwide. We team with theory and modeling efforts in other Laboratory divisions toward the ultimate goal of understanding laser/matter interaction physics.

NIF, a 1.8-MJ laser presently under engineering design, is the principal focus of the national ICF program. NIF is a flexible laser, expected to drive a capsule filled with deuterium-tritium (DT) fuel to thermonuclear ignition by two distinct methods, direct or indirect drive. In direct drive, the laser implodes the capsule by illuminating it directly. With indirect drive, the laser illuminates the interior walls of a cavity (called a hohlraum) that contains the capsule. The hohlraum walls convert the laser energy into x-rays, which illuminate the capsule very symmetrically, analogous to the process of baking an object evenly in an oven. Both direct and indirect drive have different potential failure modes, so the pursuit of both approaches increases the likelihood of achieving ignition at NIF. Considerable challenges will face us in operating NIF and in

hastening the achievement of fusion. These include diagnostic development and improving our understanding in three main areas: laser-plasma instabilities, unstable hydrodynamics, and hohlraum dynamics. P-24 has made significant contributions in all three areas with experiments using present ICF lasers. P-24 is also a principal participant in the NIF Joint Central Diagnostic Team.

P-24 has made many important contributions to the national ICF target-physics program in support of NIF. We have devoted considerable effort to studying laser-plasma parametric instability processes. These instabilities pose an important threat to ignition hohlraums because they could potentially scatter most of the laser light, decreasing both the drive efficiency and the capsule-illumination symmetry. Our experiments have verified Los Alamos theoretical models, which predict quantitatively the onset of these instabilities in NIF-relevant conditions. We have also made important advances in establishing the mechanisms by which these processes saturate, the necessary first step before quantitative predictions and control of scattered-light levels are possible.

In support of these experiments, we have recently deployed at the Nova laser at Lawrence Livermore National Laboratory (LLNL) the world's best suite of optical diagnostics for ICF. These diagnostics can image the scattered light within the hohlraum, allowing unprecedented comparisons to theoretical models. P-24 has also done pioneering work in observations of previously unknown instability processes. Several P-24 researchers were part of the team recently recognized with a LANL Distinguished Performance Award for their prediction and direct observation of the deflection of a laser beam by a plasma flowing transverse to the beam-propagation direction.

P-24 research staff have made important contributions to the understanding of unstable hydrodynamics. For example, we have conducted experiments with novel cylindrically imploding targets. These targets allow study of nonlinear, multimode Rayleigh-Taylor (R-T) instability in convergent geometry, without the diagnostic access problems of spherical capsules. Another important successful line of our hydrodynamic research involves the use of gold-coated foams to minimize the imprint of laser nonuniformities in direct-drive targets early in the laser pulse. This imprint is a seed for hydrodynamic instabilities that degrade capsule performance. P-24 also remains in charge of fielding the collaborative LANL-LLNL experiments to benchmark our predictive capability of hohlraum dynamics and capsule illumination symmetry. In addition to fielding the experiments, we have helped develop and have validated the most successful symmetry diagnostic techniques (symmetry capsules and reemission balls).

AGEX: A Research-Based Approach to Science-Based Stockpile Stewardship

The AGEX team investigates the physics of high-energy-density matter in support of the national Stockpile Stewardship and Management Plan. We perform experiments in the areas of radiation-driven hydrodynamics (instability growth, shock propagation, and nonlinear hydrodynamics), radiation transport (opacity, atomic physics, and radiation flow), and material properties (equations of state and constitutive properties of materials). We actively develop and use state-of-the-art diagnostics, including x-ray and visible imaging, spectroscopy, interferometry, and radiography. Experiments on pulsed-power and laser systems are performed both at Los Alamos and at facilities worldwide (Trident, Pegasus II, PBFA-Z, Nova, and Omega) and will be continued on future planned facilities (NIF, Trident Upgrade, Atlas, and X1).

Present experiments include the study of the R-T instability growth in the nonlinear regime using ablative drive, propagation and stability of high-Mach-number perturbed shocks, opacity of open-M-shell atomic systems in local thermodynamic equilibrium (LTE), the study of Marshak waves in the subsonic and supersonic regimes, and equation-of-state measurements of low-Z and high-Z materials. Presently we are constructing a microchannel plate gated intensifier with an optical-gate width of 35 ps to 5 ns for x-ray imaging and spectroscopy and a high-resolution ($\sim 1 \mu\text{m}$), one-dimensional x-ray imager, as well as other diagnostics. Our collaborators include LLNL, Sandia National Laboratories, the Atomic Weapons Establishment in England (AWE), and the Commissariat à l'Energie Atomique in France (CEA). We work closely with other programs, including the pulsed-power High-Energy-Density Physics and ICF programs.

Magnetic Confinement Fusion

The Magnetic Fusion Team in P-24 focuses on a variety of problems in controlling thermonuclear reactions in a laboratory, generally employing magnetic fields. The team is compact and our research projects are dynamic; these qualities allow us to maintain high visibility in the fusion community with high-quality research work. Our interests in plasma-confinement devices range from exotic alternates (including magnetized target fusion and inertial electrostatic fusion) to more conventional tokamaks, helical devices, and spheromaks. We collaborate experimentally with a number of facilities throughout the world, including JT-60U and LHD in Japan, the Alcator C-Mod tokamak at the Massachusetts Institute of Technology, the Tokamak Fusion Test Reactor (TFTR) and Feedback and Stability Experiment (FSX) tokamaks at Princeton University, the LSX-M Field Reversed Configuration at the University of Washington in Seattle, and the HBT-EP tokamak at Columbia University in New York City.

Our expertise lies in fast plasma diagnostics, neutron detection, high-speed visible and infrared (IR) imaging, plasma control, alternate confinement devices, and disruption studies. The LANL P-24 team has fielded high-power amplifiers to suppress magnetohydrodynamic (MHD) activity in plasmas and is collaborating with the Princeton Plasma Laboratory to scope out a so-called “smart shell” design for the newly proposed FSX tokamak at Princeton. Other off-site collaborations include IR imaging of tokamak diverters, triton burn-up studies in high-temperature deuterium plasmas, a variety of diagnostics on the high-power TFTR DT-plasma experiments, development of a prototype imaging bolometer, and fast imaging using a digital, high-speed, computer-controlled camera system and either periscopes or imaging bundles to view the plasmas. We have also participated in the Tokamak Physics Experimental design effort and are presently participating in the International Thermonuclear Experimental Reactor (ITER) design effort.

At Los Alamos, we have two confinement experiments in which we pursue fundamental fusion research. The first is called the Penning Fusion Experiment (PEX), which forms a spherical well using electrostatic and magnetic fields in a cryogenic trap. This experiment has demonstrated high electron densities and is working at inserting ions into the trap, which ultimately are of interest (and are necessary) for producing neutrons. Magnetized target fusion, or MTF, is our second area of research and involves the adiabatic compression of magnetized plasma to fusion conditions. Ongoing research within the Colt experiment is investigating target-plasma formation techniques and heat transfer at high energy-density conditions.

Please visit our WWW site at <http://wsx.lanl.gov> for additional information.

Applied Plasma Technologies

The Applied Plasma Technologies Team in P-24 uses plasma science and technology to solve problems in defense, the environment, and industrial competitiveness. Major technology-development and program elements include the following:

Atmospheric-Pressure Plasma Jet (APPJ)

A nonthermal, uniform-glow discharge at atmospheric pressure in a cylindrical cavity with high gas-flow rates produces reactive radicals and metastable molecules persisting for fractions of a second at atmospheric pressure (Fig. I-10). These reactive species remove surface contaminants and films, providing a new means of cleaning objects and substrates. Current programs include removal of actinide and metallic contaminants, chemical decontamination for the neutralization of chemical agents on surfaces, and graffiti removal.

Intense, pulsed ion beams and accelerated plasmas

Several promising applications of intense ion beams and pulsed, accelerated plasmas that require repetitive beams and plasmas have emerged in the past few years. These include processing of materials, such as surface modification through rapid melt and resolidification, ablative deposition for producing high-quality coatings, and nanophase powder synthesis; production of intense neutral beams for the next generation of tokamaks; and intense, pulsed neutron sources for the detection of nonmetallic mines, neutron radiography, and spent nuclear fuel assay. We are developing a repetitive ion accelerator and an accelerated plasma source to investigate these applications.

Plasma-Source Ion Implantation (PSII) and cathodic arcs

PSII is a non-line-of-sight method for implanting ions from a plasma into a metal for surface modification. Typically, ions from a gaseous plasma are used, but cathodic arc technology allows metal ions to be implanted as well. PSII may be combined with plasma-based surface-coating technologies to form highly adherent, thick coatings of materials such as diamond-like carbon and ceramic metal oxides. Programs include plasma-implanted and plasma-deposited erbia coatings in support of the weapons surety program; molten-plutonium-resistant coatings for near-net-shape casting molds; highly adherent coatings for wear- and corrosion-resistant gun barrels for the Army; and plasma-based surface treatment and coatings for industrial tooling (this is part of a National Institute of Science and Technology [NIST] Advanced Technology Program with more than a dozen industrial partners).

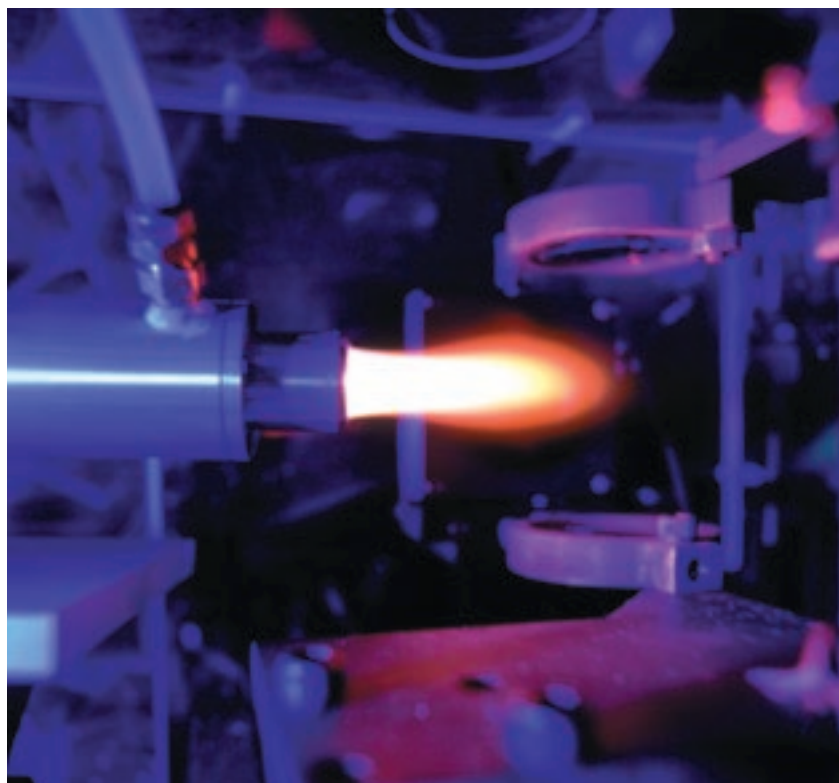


Fig. I-10. The atmospheric-pressure plasma jet has applications that include removal of actinide and metallic contaminants, chemical decontamination, and graffiti removal.

P-25: Subatomic Physics

John B. McClelland,
Group Leader
Andrea P. T. Palounek,
Deputy Group Leader

Introduction

The Subatomic Physics Group (P-25) is primarily engaged in research into nuclear and particle physics. There is also a strong and growing effort to turn the group skills and capabilities to applied programs such as proton radiography. The group currently is conducting research and developing new programs at Los Alamos and at other laboratories, such as Brookhaven National Laboratory (BNL), Fermi National Accelerator Laboratory (FNAL or Fermilab), and the European Center for Nuclear Research (CERN). The people and programs in the Subatomic Physics Group were recently rated highly in a nationwide review of the DOE Nuclear Physics Program. Some highlights of the group's activities and future directions follow.

Pion Physics

The neutral meson spectrometer (NMS) had its final LANSCE (Los Alamos Neutron Science Center) run of 3.5 months before it was shipped to BNL, where it will be used in another experiment. We are now analyzing the new data as well as data from previous runs, with emphasis on the $^{32}\text{S}(\pi^-, \pi^0)$ reaction. The report of this work will be available by late 1997. We are rewriting the NMS data analyzer program to improve this and other analyses. That work will be applicable to the BNL experiment.

Hypernuclear Physics: Experiment E907 at the Alternating-Gradient Synchrotron (AGS) at BNL

We led the effort to propose this new hypernuclear experiment at the AGS using the LANSCE NMS to measure the (K^-, π^0) reaction. This experiment will demonstrate the feasibility of using the (K^-, π^0) reaction as a novel tool to produce Λ -hypernuclei with resolution significantly better than the existing (K^-, π^-) and (K^+, π^+) experiments and will measure the Λ -hypernuclear π^0 weak decay modes that have never been studied before. The proposal was approved by the AGS Program Advisory Council in late 1994. The NMS and associated equipment were moved from LANSCE to the AGS in December 1995, and the first test run was completed in May 1996. The LANL group will assume the major responsibilities for the NMS operation and for the physics direction in this experiment.

Quark-Gluon Physics

This has been a highly visible and productive program at Fermilab. Our group was the first to exploit high-energy hadronic processes to explore the quark structure of nuclei. We are investigating the nuclear dependence of lepton-pair production with proton beams to understand how the quark and gluon structure in nuclei differs from that in free nucleons. During 1995–1996 we made substantial progress in the construction and refurbishing of the Fermilab Meson-East spectrometer, where E866 began taking data in July 1996. That experiment will search for deviations in the anti-up and anti-down quark distributions in the proton to provide insight into hadronic and partonic descriptions of the nucleonic sea.

We also continued major analysis efforts on past experiments E772 and E789. We developed Monte Carlo and analysis software that will enable the extraction of cross sections from 1.5 million Drell-Yan and Upsilon production events from the copper beam dump of E772. We completed the analysis (and publication) of the first B -meson cross-section data for 800-GeV proton-nucleus interactions and published the nuclear dependence of J/ψ production in the negative x -Feynman region.

PHENIX Spin Program

The highly successful Los Alamos/RIKEN (Institute for Physical and Chemical Research—Tokyo [Wako], Japan) collaboration was the culmination of two years of work and resulted in the final specification of the RIKEN contribution to the spin-structure function program of the PHENIX detector. RIKEN funding will purchase the PHENIX south-arm magnet plus associated muon tracking and identification systems. This contribution greatly enhances the high-mass dimuon acceptance of the PHENIX detector (Fig. I-11) and permits a large menu of unique spin-structure function experiments to be carried out. Equally important, the muon upgrade will add substantially to the physics reach of the relativistic heavy-ion program.

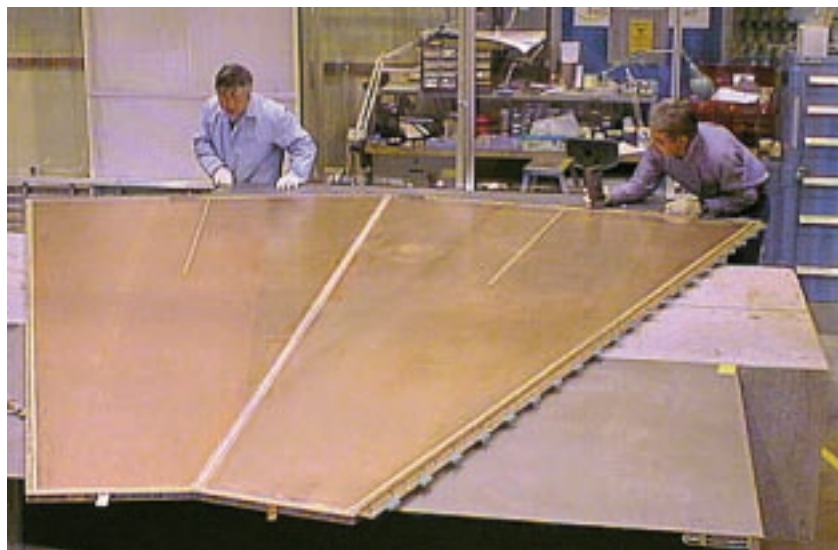


Fig. I-11. P-25 technicians building part of the PHENIX detector.

Electroweak Physics: LSND

The Liquid Scintillator Neutrino Detector (LSND), commissioned at LANSCE in 1993, has led to published papers describing the detector and source systems and the full decay-at-rest analysis of all data taken up to December 1995. The LSND paper "Evidence for Neutrino Oscillations from Muon Decay at Rest" has been published. A first-pass analysis on decay-in-flight data gave encouraging results. That analysis is more difficult than decay at rest since the signal properties are less elaborate. In addition, the magnitude of the excess is likely to have a strong impact on our estimate of Δm^2 and so demands the greatest care. That analysis should be complete during 1997, including papers describing the analysis.

BOONE (Booster Neutrino Experiment)

The definitive experimental establishment of nonzero neutrino mass will have far-ranging impact into other fields such as astrophysics; there is a strong need for experiments to follow up our successes with LSND. We have studied the possible BOONE detector and source systems and explored the level of electron neutrinos that can be expected from the beam and background at Fermilab. The detector seems to be quite adequate for both Δm^2 scenarios suggested by LSND. The detector methodology could follow the LSND method because of performance improvements that the LSND analysis has engendered.

MEGA

The apparent conservation of muon number remains a central problem of weak-interaction physics. Searching for processes that violate muon-number conservation will give insight into the possible extensions of the minimal standard model of weak interactions. MEGA (muon decays into an electron and a gamma ray) was designed to make such a search at the Los Alamos Meson Physics Facility (LAMPF), now known as LANSCE. The final year of taking data for this experiment was 1995–1996. The combined data from the summers of 1993–1995 should yield a statistical precision that improves the current world sensitivity to this process by a factor of 70 to roughly 7×10^{-13} . The MEGA collaboration made substantial strides in the development of algorithms to extract the results. The three major components of the analysis needed are reconstruction of the kinematic properties of the photon, kinematic properties of the positron, and their relative timing. The photon analysis is nearly complete, and the other two have reached an advanced stage.

RHO

The MEGA positron spectrometer was used to measure the Michel parameter ρ . The parameter governs the shape of the polarization-independent part of the energy spectrum for positrons emitted in normal muon decay. The standard model predicts ρ to be 0.75; it is currently known to be within 0.3% agreement with that value. Deviations from 0.75 might indicate the need for right-handed currents in the standard model. Collected data will enable a statistical precision that will allow the value of ρ to be measured to 0.05%, but the systematic errors are being evaluated. Such a precision will allow the checking of the reported deviations from the standard model in neutron decay. The analysis should be complete by the end of 1997.

Measurements of Beta Asymmetry and Atomic Parity Nonconservation

A key step in undertaking the measurements of beta asymmetry and parity nonconservation is the efficient trapping of selected radioactive species. This is done using a magneto-optical trap. Using a high-intensity laser, we have developed one of the world's largest traps, which can trap up to 4×10^{10} atoms of stable cesium. We are further improving the trapping efficiency by coating the inside of the glass trapping cell with a special nonstick coating of octadecyltrichlorosilane (OTS) and by using two lasers operating at slightly different frequencies to reduce light-assisted losses, which become limiting at high beam intensities.

Theory

The Subatomic Physics Group has a small theory component. We are developing a theory for connecting hadron properties in free space. We have also explored phenomenological approaches that can be used to determine (from data) masses and coupling constants for higher-mass resonances in nuclei. We are developing a theory for connecting mean-square matrix elements of the parity-violating interaction, measured by TRIPLE in compound nuclear resonances, to the underlying parity-violating force, exploiting the chaotic properties of the compound nucleus. We have been looking at the reaction theory of pion scattering from nuclei with an eye toward simplifying the description of specific reactions so that these reactions can be more easily used for specific purposes, such as evaluating hadron transport in nuclear collisions and interpreting the results of dibaryon resonance searches.

One group member investigated the phenomenon of neutrino oscillations within a three-state mixing model and found that all reported neutrino-oscillation data are consistent with a mass-mixing-angle analysis in terms of three neutrinos. His "Gravitationally Induced Neutrino-Oscillation Phases" is the First Award Essay for 1996 by the Gravity Research Foundation.

Participants at a relativistic heavy-ion meeting held during the summer of 1995 determined that essentially all relativistic heavy-ion transport event generators are incapable of reproducing the pion production data taken at LANSCE. We are investigating the reasons for this; the answer could have a significant impact on our heavy-ion and PHENIX experimental programs.

Applied Programs: Proton Radiography

The decision to forgo underground nuclear testing and to restrict the nuclear stockpile to an increasingly smaller number of weapons has forced DOE and its laboratories to rethink their role in stockpile stewardship. Much of this reassessment has been embodied in the philosophy of science-based rather than test-based stockpile stewardship.

Proton radiography offers several advantages over conventional x-ray techniques for radiographing thick, dense, dynamic systems. These advantages are (1) high penetrating power, (2) high detection efficiency, (3) very small scattered background, (4) the lack of a need for a conversion target and the consequent phase space broadening of the beam, (5) inherent multipulse capability, and (6) the ability to tolerate large stand-off distances from the test object and containment vessel for both the incoming and outgoing beam. Additionally, proton radiography provides the unique possibility of measuring both the density and the material composition of a test object with a pulsed system.

Protons interact with matter through both the long-range Coulomb force and the short-range strong interaction. Focusing protons using a magnetic lens (Fig. I-12) both allows the magnitude and Z-dependence of the interaction to be changed simply by looking at an object through different angular apertures and leads to the capability of assessing material composition. Multiple images can be made on a single axis by using multiple detectors, lenses, and irises.

P-25 leads this effort, together with a strong cross-divisional team including P, X, DX, ESA, T, and LANSCE Divisions.

Education and Outreach

P-25 continues to be active in education and outreach activities. We are formal members of three education programs run by the Laboratory. Group members visited every teacher and school in the TOPS (Teacher Opportunities to Promote Science) and TOPS Mentor programs at least once in 1995–1996; conducted regional meetings for TOPS teachers, TOPS Mentors, and TOPS alumni; and led several workshops in Los Alamos and Albuquerque. During a recent workshop, TOPS mentors built (from scratch) a simple lightning detector designed by physicists from NIS-1 and P-25. We were also active in the PRISM (Preservice Institute for Science and Math) program, guiding its students through a comparison of the transmission qualities of various brands of sunglasses.

Fig. I-12. Schematic diagram of the lenses and collimator on the dynamic proton-radiography beamline.

